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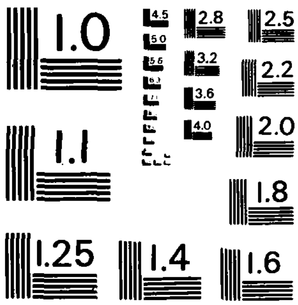

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FURTHER DEVELOPMENT OF A COMPUTER ALGORITHM FOR THE AUTOMATIC DETERMINATION OF SPACE VEHICLE POTENTIAL IN REAL TIME

DECEMBER 1983

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The performance of two related computer algorithms for the purpose of critical potential detection has been analyzed. These algorithms employ positive ion spectra from onboard electrostatic analyzers to determine whether a critical potential has been reached or exceeded. The day to day performances have been examined and individual ion count spectra have been checked in cases of algorithm failure to see what algorithm modifications might lead to improved performance. Additionally, it has been considered whether reliable charge detection could be obtained using a rapid response Electrostatic Analyzer with many fewer energy channels than the 64 channel SC9 experiment of the P78-2 spacecraft. This has led to development of a goodness-of-fit test based on an onboard model of the distribution function profile in the absence of charging. Preliminary tests of this algorithm suggest that it may be useful as a rapid response detection algorithm on its own or as a preliminary test to screen for suspected cases of charging to be further analyzed by one of the other algorithms.

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INTRODUCTION

It is important for Air Force applications to have a reliable, real time method of determining whether a space vehicle at geosynchronous orbit has acquired a high negative potential (in excess of some critical value of the order of 0.5 keV) with respect to its plasma environment. The cause for concern is that the resultant electrical discharge between differentially charged components of the vehicle might disable onboard instrumentation and bring about mission failure. Hence, there is the need to determine the presence of a dangerous vehicle potential quickly so that suitable discharge mechanisms can be activated.

We have previously reported on the development of two related computer algorithms for the purpose of critical potential detection (Spiegel, 1981). These algorithms, the "Count Ratio" algorithm and the "Distribution Function" algorithm employ positive ion spectra from onboard electrostatic analyzers to determine whether a critical potential has been reached or exceeded. We have tested these algorithms using electrostatic analyzer (ESA) ion count data from the SC9 experiment of the P78-2 spacecraft for thirty different time periods (a total of 9925 ion count spectra) during which vehicle charging took place in a variety of plasma environments. We have previously reported that overall, the count ratio algorithm was 92% successful in determining vehicle potential to within 20% of informed estimates of "true potential", and was 96.5% successful in determining whether a critical (negative) potential of 0.5 keV had been reached. The

corresponding figures for the distribution function algorithm were 95.2% and 98.1% respectively.

In the present report, we have further analyzed the performance of the two algorithms on our 30 day data base. We have examined the day to day performances and checked individual ion count spectra in cases of algorithm failure to see what algorithm modifications might lead to improved performance. Additionally, we have considered whether we could obtain reliable charge detection using a rapid response ESA with many fewer energy channels than the 64 channel SC9 instrument. This has led to development of a goodness-of-fit test (chi-square algorithm) based on an onboard model of the distribution function profile (in the absence of charging). Preliminary tests of this algorithm suggest that it may be useful as a rapid response detection algorithm on its own, or as a preliminary test to screen for suspected cases of charging to be further analyzed by one of the other algorithms.

TEST OF THE COUNT RATIO AND DISTRIBUTION FUNCTION ALGORITHMS

The count ratio and distribution function algorithms have been described previously (Spiegel 1981). Basically, they depend on the shift in the ion count spectra (and the distribution function profile computed therefrom) recorded by an ESA on a negatively charged spacecraft: all incoming ions will have their energy increased by the amount of the vehicle potential, and so there will be very few ion counts recorded in ESA channels below the energy level of vehicle potential. Hence in cases of vehicle charging, there will be a sudden large increase in ion counts as the channels are scanned (in order of increasing energy) when the level of charging is reached. Also, the computed ion distribution function, which is normally a decreasing function of energy, will show a statistically significant increase at the channel corresponding to vehicle potential. Typical ion counts spectra and distribution function profiles are shown in Figs. 1 and 2 for an uncharged vehicle, and in Figs. 3 and 4 for a vehicle charged to a potential corresponding to SC9 ESA channel 32 (-1205 eV). The increase in ion counts and distribution function are exploited by the count ratio and distribution function algorithms respectively. Flow charts of these algorithms are shown in Fig. 5 (count ratio algorithm) and Fig. 6 (distribution function algorithm).

The results of tests of these algorithms on our 30 day, 9925 ion

count spectra data base, are presented in Tables 1-4. The algorithm parameters used had been found to provide statistical reliability and reasonable results in earlier tests. For the count ratio algorithm (CRA), these were a critical ratio of 4.5, with a count minimum of 90 in the higher energy channel. For the distribution function algorithm (DFA), a margin of 4 standard deviations was required for assuming a statistically significant increase in distribution function. The test results indicate largely successful performance both overall, and on a day by day basis.

Table 1 shows how the algorithms perform as potentiometers. This was not the function for which they were developed - a successful determination of whether a critical potential has been exceeded need not require that the vehicle potential be accurately known, but only if it is greater or less (in magnitude) than the critical value. Still, both algorithms fare quite well, being with 10% of true potential for nearly 90% of the total spectra. The DFA has a slight overall advantage, but on a day by day basis, the CRA is frequently superior.

The tests of algorithm performance with respect to critical potential (Vcr) determination are presented in Tables 2 and 3 on a day by day basis for Vcr = 500 eV, and in summary form in Table 4 for Vcr values of -250 and -500 eV. Again, the day by day performances are variable, but in general, the DFA is seen to give better overall performance for both Vcr values. Further examination reveals that the DFA gives significantly better results when the vehicle has in fact attained critical charge. The DFA error rate for missing critical

charging is only 4.4% at -500 eV and 6.6% at -250 eV; the corresponding CRA error rates are 14.3% and 17.4% respectively. On the other hand, the CRA is superior when the vehicle is not critically charged, giving "false alarms" only 0.1% of the time for both critical potentials studied. The DFA performs well in this respect also, with spurious determinations of charging at rates of only 1.1% for Vcr = -500 eV and 1.4% for Vcr = -250 eV.

In order to improve algorithm performance, we have examined many of the ion count spectra for cases of algorithm failure. Cases of false alarm were very unusual for both algorithms. The CRA never exhibited false alarms on successive spectra; by simply requiring two consecutive positive test results before concluding that critical charging had occurred, one could insure against spurious reports of charging. However, the CRA failure rate of 15% or so in detecting actual critical charging is somewhat worrisome. Not surprisingly, the spectra associated with these instances of failure were always more or less ambiguous with respect to whether critical charging had, in fact occurred. Often, the "true potential" estimate that indicated critical charging, was made only upon examination of neighboring count spectra whereas the algorithms being tested were designed to examine only one instrument sweep at a time. The cases corresponding to algorithm failure studied were all "close calls," especially when viewed in isolation from neighboring spectra and/or information from other onboard instrumentation. Another point worth noting: most of these "failures" occurred after positive determinations of charging

based on earlier spectra. In cases such as these, vehicle discharging would have already commenced, and the "failure" would have been of no consequence to the spacecraft.

A lower "missed charging" failure rate could clearly be achieved by lowering the critical count ratio and/or upper channel count threshold needed for a positive determination of charging. This would inevitably be accompanied by an increase in the false alarm rate. To a certain extent, the DFA results exhibit this tradeoff. The false alarm rate is in excess of 1%, but the missed charge error rate is only about 5 or 6%. As mentioned above, many of these "errors" results from comparison with true potential estimates that are themselves somewhat in doubt. Certainly better agreement with these estimates could be obtained by relaxing the condition for finding a statistically significant distribution function increase. With equal certainty, this would lead to an increase in the number of spurious reports of charging. We had hoped to be able to quantify these statements for both algorithms by experimenting with different algorithm parameter values to see the effects on algorithm performance. However, constraints on availability of computer time and of the data base precluded pursuing these investigations. Moreover, the current level of success of these algorithms, especially the DFA, lessened the immediate need for such experimentation. One question which remained pressing was whether a rapid response ESA with significantly fewer channels than the 64 channel SC9 instrument could give a

reliable determination of critical vehicle charging in less real time. Attempts to use data from the 8 channel SC5 ESA (even when appropriately smoothed) had not given satisfactory results when used in conjunction with count ratio or distribution function algorithms. Hence we attempted to develop an alternative approach employing ion count data from an ESA with fewer energy channels.

THE GOODNESS OF FIT TEST (CHI SQUARE ALGORITHM)

We have already noted that the ion plasma distribution function as computed from ESA ion counts on a negatively charged space craft will look different from that computed from uncharged spacecraft measurements, due to the resultant shift of the count spectrum toward higher energy. If we had a reasonable idea of the distribution function (and hence the expected count spectrum) in an energy range encompassing observed super-critical spacecraft charging, we might be able to use a chi-square goodness of fit test to see whether a given observed count spectrum departed sufficiently from that expected to suggest that the spacecraft was critically charged. Thus, instead of comparing counts, or distribution functions, a pair of channels at a time, one would compare the entire set of ion count measurements with expected values based on an empirical ion distribution function model. In cases of poor fit with the expected values, the individual channels could be compared in pairs to see whether the poor fit could be

attributable to critical charging. The virtue of this approach is that it might work successfully with a low resolution rapid response ESA to quickly and reliably indicate "uncharged" spectra, and to flag suspicious cases for further investigation.

To serve as a model for the pre-charging ion distribution function, we utilize the findings of Mullen and Gussenhoven (1982) and assume that the variations of distribution function with energy behaves as a power law (linear on a log-log plot) over the energy range 0.1-100 keV:

$$f(E) = kE^{\alpha} \tag{1}$$

Here E represents energy, f(E) is the ion distribution function and k is a constant of proportionality; the exponent α as measured from log-log plots of distribution function versus energy presented by Mullen and Gussenhoven (1982) is approximately -1.5.

Now the number of ion counts per unit time C(E) expected over a small energy interval ΔE centered at energy E is given by

$$C(E) = 2G(E)f(E)E\Delta E/M^2 \tag{2}$$

where M is the proton mass and G(E) the geometric factor of the ESA. If we assume G(E) to be approximately constant over the energy range of interest, and substitute Eq. (1) in Eq. (2), we can write

$$C(E) \simeq KE^{1+\alpha} \Delta E \tag{3}$$

where $K = 2kG(E)/m^2$ is taken to be constant. From Eq. (3), we can derive an approximate expression for the count rate to be expected over an extended energy interval E_a to E_b:

$$C(E_a, E_b) \simeq K \int_{E_a}^{E_b} E^{1+\alpha} dE$$

$$\simeq \frac{K}{2+\alpha} \left(E_b^{2+\alpha} - E_a^{2+\alpha}\right) \qquad (4)$$

This expression gives the number of ion counts (per unit time) to be expected in an ESA channel, or bin, of width E_a to E_b.

The literature on optimal design of chi-square goodness-of-fit tests is surprisingly sparse, and ambiguous in its recommendations. One often quoted approach is that of Mann and Wald (1942), which was summarized and augmented by Williams (1950). In brief, this approach recommends apportioning the data into class intervals which have been selected such that under the null hypothesis, equal frequencies would be expected in each interval. The optimal number of classes k depends on the number of data values N and the level of significance of the test α and is given (Mann and Wald, 1942) by the expression

$$k = \left[4\left\{\frac{2(n-1)^2}{(Z_\alpha)^2}\right\}^{\frac{1}{5}}\right] \qquad (5)$$

where Z_α represents the critical value of the standard normal variable at significance level α. Williams (1950) has shown that for practical purposes, the number of classes could be halved without an appreciable loss of power of the test. Hence, for example, using the latter criterion at the .005 significance level ($Z_{.005}$ = 2.327), with 100 data points, an optimal ESA would divide the energy range under consideration into 10 channels with equal expected frequencies (10

counts per channel in the example). For a sample size with N = 60 at $\alpha = .01$, 8 channels would suffice. Thus if our power law model of the "uncharged" ion distribution function is reasonably accurate, one could design an ESA of low resolution (8-10 channels) and rapid response (100 or fewer counts required per test) that would provide data for an algorithm employing (in part) a chi-square goodness of fit test to detect critical charging.

To see whether this type of test might be successful, we utilized high resolution (64 channel) SC9 ion count data, distributing these counts into equal expected frequency energy class intervals based upon our power law distribution function model. As we have seen in Eq (4), the expected count rate in an energy interval or bin ($\tilde{E}_a$, $\tilde{E}_b$ is proportioned to $\tilde{E}^{2+\alpha}$ - $\tilde{E}^{2+\alpha}$. (We use the tilde to distinguish the class boundaries we are determining from the mid-channel energies of the SC9 ESA, denoted by E_i.) If we let $\tilde{E}_1$ be the minimum and $\tilde{E}_{N+1}$ the maximum energy boundaries for the desired energy range which we wish to subdivide into N equal expected frequency classes, then the N-1 interior class boundaries are given by

$$\tilde{E}_{k+1}^{2+\alpha} = \tilde{E}1^{2+\alpha} + k\delta \qquad k = 1, 2, \ldots, N-1 \tag{6}$$

where

$$\delta = \frac{\tilde{E}_{N+1}^{2+\alpha} - \tilde{E}_1^{2+\alpha}}{N} . \tag{7}$$

This provides N bins with boundaries $\{\tilde{E}_1, \tilde{E}_2, \ldots, \tilde{E}_N, \tilde{E}_{N+1}\}$.

The mid channel energies of the 64 SC9 channels are given by (Mullen et al, 1980):

$$E_j = -21 + (16.1)(1.145)^{j-1} + \frac{28}{j + 128} \qquad j = 1, 2, \ldots, 64 \qquad (8)$$

and in the region of interest ($E \gtrsim 500$ eV; $j \gtrsim 25$), we have approximately

$$E_j \doteq (16.1)(1.145)^{j-1} = (14.06)(1.145)^j \qquad (9)$$

Hence to each of the N+1 bin boundaries $\tilde{E}_k$ we can assign an SC9 channel "index" X_k:

$$X_k = \frac{1}{1.145} \left(\frac{\tilde{E}_k}{14.06}\right)^{1/k} \qquad k = 1, 2, \ldots, N+1 \qquad (10)$$

Assuming the SC9 ion counts to be uniformly distributed over their respective energy channels, it is straightforward to assign these counts to the appropriate low resolution bins on the basis of the bin boundary index values. (We are aware that the SC9 ESA response curves are not flat with sharp cut-offs at channel boundaries, but we felt that this is a reasonable approximation to make in order to proceed with testing the goodness of fit algorithm.)

To examine the potential usefulness of this method, we utilized SC9 high energy ion count data from day 79114. We computed chi-square for the 266 count spectra for which true potential estimates were available. We divided the energy range 0.5 to 10 keV into eight bins, and distributed the observed counts into these bins, as described above. Then chi-square was calculated:

$$X^2 = \sum_{k=1}^{8} \frac{\tilde{C}_k - \bar{C}^{\,2}}{\bar{C}} \qquad (11)$$

where C_k is the number of counts in the kth bin, and C is the number expected in each bin under the null hypothesis:

$$\overline{C} = \frac{1}{8} \sum_{k=1}^{8} \tilde{C}_k \qquad (12)$$

The values of chi-square thus obtained give a measure of the overall departure of a given count spectrum from that associated with the approximate power law distribution function which would be observed by an uncharged spacecraft.

The utilization of the SC9 data for this purpose is far from ideal. Not only is uncertainty introduced by transferring counts from SC9 channels to the low resolution bins; of even greater importance is the fact that the sample size (number of data points utilized per spectrum) is highly variable, ranging from several hundred to several thousand. The sample size always greatly exceeded the number for which our eight bin classification would be appropriate. Furthermore, the power law distribution function model was known to be only a rough approximation to reality and hence we would expect the calculated chi-square values to be quite large even in the absence of charging. While this was indeed observed - values of the order of several hundred were not uncommon for uncharged spectra - count spectra measured at times of critical charging were almost always an order of magnitude (or more) higher.

The results of our less than perfect test of the chi-square algorithm were very encouraging. Based on comparison of calculated chi-square values with true potentials, a critical chi-square value of

1000 seems appropriate to infer critical charging at the 500 eV level. With this choice, of the 266 spectra examined, there were only six cases of failure to detect critical charging, and only one clear-cut false alarm (in four other apparent false alarms, it appears that onboard experimentation, resulting in an excessive count rate at low energies, produced the detected spectral distortion.)

We present in Table 5 the bin populations for four spectra for day 79114, corresponding to successful algorithm performance when there is critical charging (25975 U.T.), success when there is not critical charging (24173 U.T.), failure when the algorithm misses critical charging (27143 U.T.), and failure when the algorithm gives a false alarm (22685 U.T.). In Table 6, we show corresponding portions of the ion count spectra for the same time periods. The two exhibited cases of algorithm success illustrate the typically large values of chi-square computed from uncharged ion count spectra (the power law model is indeed only a rough approximation to the distribution function), and the much larger values occurring when the spectra are distorted by critical spacecraft charging. The case of failure to detect charging may be partly attributable to the unusually low number of total data points in this spectrum; a lower critical chi-square value may have been appropriate here (the critical charge was also missed by the count ratio algorithm for this spectrum.) The false alarm was caused by an unusually large increase (but no sharp peak) in the higher energy SC9 channels - the spacecraft may have been moving into a region of greater plasma density during this SC9 ESA "sweep".

It is clear that the false alarm would be eliminated if a subsequent "count rate" test of the eight bin counts were made; the absence of a charging peak would correctly indicate no critical charging.

CONCLUSIONS

We have analyzed certain tests of three algorithms for the real time determination of critical spacecraft charging and found all three to show promise of successful application. The count ratio algorithm makes no explicit assumptions concerning the ion distribution function; it requires a count spectrum of sufficiently high resolution and sample size that a statistically significant count peak at the level of charging can be clearly identified. The distribution function algorithm utilizes the fact that the distribution function is a decreasing function of energy, and requires ESA channels of sufficiently narrow energy range that increases in the distribution function will be detectable upon computation from the count rate. Using SC9 data and a reasonable choice of parameters for each algorithm, the distribution functions algorithm is found to perform somewhat better overall than the count ratio algorithm (which is also an able performer). Finally, we have introduced a chi-square (goodness of fit) algorithm, in an attempt to see whether a more explicit assumption about the energy dependence of the distribution function would enable us to use fewer, less well resolved (and thus more rapidly obtained) ion counts to determine charging. We used an approximate power law

energy dependence for the distribution function and simulated a low resolution ESA using SC9 ESA data from one day of our thirty day data base. In this first test, the chi-square algorithm was quite successful as a stand alone test, surpassing the count ratio algorithm, and almost as good as the distribution function algorithm, for data from day 79114.

There remains much useful work to be done with all three algorithms. Numerical experimentation would be useful in determining optimal parameter choice for the count ratio and distribution function algorithms. It would also be helpful to assess their performances on an expanded SC9 data base. The chi-square algorithm should be tested on the entire thirty-day data base upon which the other algorithms have been evaluated. It should also be tested on data from a low resolution ESA, such as in the SC5 experiment. Those channel boundaries would not correspond to an equal expected count frequency classes, but one could still compute chi-square by comparing observed counts with those to be expected based on a reasonable distribution function model. We have previously found (Spiegel 1981) that SC5 count data is not suitable for successful application of the count ratio or distribution function algorithms. We should determine whether better results could be achieved with the chi-square method.

It seems clear that the chi-square test could be made more reliable if we relied on a lower critical value (thereby reducing the number of missed charging failures) and employed a subsequent count ratio type test to confirm charging in suspect spectra (thus weeding out the resultant larger number of false alarms). We would like to

explore this hypothesis to learn whether we can indeed obtain high levels of accuracy with a rapid response test. This testing can be performed utilizing SC9 and SC5 data; additionally it would be most useful to analyze laboratory and/or field data from a low resolution ESA designed to facilitate our goodness of fit testing.

TABLE 1. COMPARISON OF COUNT RATIO AND DISTRIBUTION FUNCTION ALGORITHM PERFORMANCE IN DETERMINING VEHICLE POTENTIAL

Day	No. of Spectra	C.R. Algorithm Accurate to $\pm$ 10%	C.R. Algorithm Accurate to $\pm$ 20%	D.F. Algorithm Accurate to $\pm$ 10%	D.F. Algorithm Accurate to $\pm$ 20%
79086	568	92%	92%	93%	93%
087	284	82	86	83	92
098	246	90	95	91	100
100	230	91	93	90	95
104	268	88	96	80	99
105	220	90	92	90	97
106	254	89	97	78	95
108	267	81	86	82	96
114	266	67	71	76	86
117	250	72	72	93	93
118	179	92	92	93	93
120	280	91	91	94	94
172	430	91	91	98	98
241	101	72	72	81	81
267	333	80	80	91	91
270	355	89	98	79	93
271	582	83	85	82	88
272	342	94	98	82	90
273	330	77	80	82	89
274	332	93	95	89	96
276	342	91	97	83	93
277	344	92	95	91	98
282	552	93	99	88	99
283	330	87	90	93	99
285	506	94	97	93	100
286	338	93	93	99	99
294	613	100	100	100	100
302	344	94	99	92	98
305	346	96	98	95	99
80164	85	100	100	100	100
Overall	9925	89.1	92.0	89.2	95.2

TABLE 2. PERFORMANCE OF COUNT RATIO ALGORITHM FOR Vcr = -500 eV

		VEHICLE CRITICALLY CHARGED		NOT CRITICALLY CHARGED		
Day	No. of Spectra	Algorithm Correct (Detects Charging)	Incorrect (Misses Charging)	Algorithm Correct	Incorrect (False Alarm)	Combined Correct Performance
79086	568	0	14	554	0	98%
087	284	47	39	198	0	86
098	246	149	12	85	0	95
100	230	32	13	185	0	94
104	268	161	10	97	0	96
105	220	79	4	137	0	98
106	254	165	1	88	0	99
108	267	124	31	112	0	88
114	266	83	34	148	1	87
117	250	1	4	245	0	98
118	179	0	0	179	0	100
120	280	0	5	274	1	98
172	430	0	0	430	0	100
241	101	7	6	87	1	93
267	333	0	1	332	0	99.7
270	355	155	1	199	0	99.7
271	582	93	38	450	1	93
272	342	112	7	221	2	97
273	330	37	61	231	1	81
274	332	58	2	272	0	99
276	342	99	0	243	0	100
277	344	82	11	251	0	97
282	552	198	5	349	0	99
283	338	47	19	272	0	94
285	506	153	14	339	0	97
286	338	0	0	338	0	100
294	613	0	0	613	0	100
302	344	69	2	271	2	99
305	346	55	2	289	0	99
80164	85	0	0	85	0	100
Overall	9925	2006	336	7574	9	96.5
Overall for Vcr= -250eV:		2409	506	7003	7	94.8

TABLE 3. PERFORMANCE OF DISTRIBUTION FUNCTION ALGORITHM FOR Vcr = -500eV

Day	No. of Spectra	VEHICLE CRITICALLY CHARGED Algorithm Correct (Detects Charging)	VEHICLE CRITICALLY CHARGED Incorrect (Misses Charging)	NOT CRITICALLY CHARGED Algorithm Correct	NOT CRITICALLY CHARGED Incorrect (False Alarm)	Combined Correct Performance
79086	568	7	7	552	2	98%
087	284	73	13	193	5	94
098	246	158	3	85	0	99
100	230	42	3	183	2	98
104	268	170	1	97	0	99.6
105	220	83	0	137	0	100
106	254	165	1	88	0	99.6
108	267	149	6	112	0	98
114	266	115	2	149	0	99
117	250	2	3	245	0	99
118	179	0	0	178	1	99
120	280	0	5	274	1	98
172	430	0	0	430	0	100
241	101	9	4	85	3	93
267	333	0	1	329	3	99
270	355	155	1	187	12	96
271	582	119	12	440	11	96
272	342	107	12	206	17	92
273	330	83	15	224	8	93
274	332	59	1	272	0	99.7
276	342	98	1	234	9	97
277	344	91	2	249	2	99
282	552	203	0	349	0	100
283	338	62	4	272	0	99
285	506	164	3	339	0	99
286	338	0	0	338	0	100
294	613	0	0	612	1	99.8
302	344	69	2	271	2	99
305	346	57	0	288	1	99.7
80164	85	0	0	85	0	100
Overall	9925	2240	102	7503	80	98.2
Overall for Vcr: -250eV		2722	193	6911	99	97.1

TABLE 4. SUMMARY OF ALGORITHM PERFORMANCES ON 30 DAY DATA BASE

	Count Ratio Algorithm	Distribution Function Algorithm
Correct to within 20% of true potential	92.0%	95.2%
Correct to within 10% of true potential	89.1	89.2
Overall correct determination for Vcr = -500eV	96.5	98.2
Correct when critically charged	85.7	95.6
Incorrect when critically charged	14.3	4.4
Correct when not critically charged	99.9	98.9
Incorrect when not critically charged	0.1	1.1
Overall correct determination for Vcr = -250eV	94.8	97.1
Correct when critically charged	82.6	93.4
Incorrect when critically charged	17.4	6.6
Correct when not critically charged	99.9	98.6
Incorrect when not critically charged	0.1	1.4

TABLE 5. EXAMPLES OF CHI-SQUARE ALGORITHM PERFORMANCE

Bin	Energy Range (keV)	Ion Counts in Energy Bins			
		Algorithm Correct		Algorithm Incorrect	
		25975 U.T. (Charged)	24173 U.T. (Uncharged)	27143 U.T. (Charged)	22685 U.T. (Uncharged)
1	0.50- 1.03	36	37	29	55
2	1.03- 1.74	32	39	25	64
3	1.74- 2.65	20	60	74	71
4	2.65- 3.74	12	92	231	89
5	3.74- 5.02	49	103	103	134
6	5.02- 6.50	711	160	61	222
7	6.50- 8.15	289	232	68	476
8	8.15-10.00	183	233	53	562
Total Counts		1332	956	644	1673
Chi-Square		2439	377	376	1338
True Potential (eV)		5417	0	2743	0

TABLE 6. PORTIONS OF SC9 ION COUNT SPECTRA FOR THE EXAMPLES OF TABLE 5.

Channel	Energy (eV)	Time of Spectrum (U.T.) 25975	24173	27143	22685
25	454	2	16	9	8
26	523	7	6	2	9
27	602	7	8	6	6
28	692	8	9	8	10
29	796	4	5	7	13
30	914	9	6	4	13
31	1050	4	6	6	13
32	1205	9	10	3	13
33	1383	8	7	9	17
34	1586	11	15	8	21
35	1820	9	18	4	30
36	2086	4	19	5	19
37	2392	7	21	36	19
38	2742	6	23	153	33
39	3143	7	43	63	31
40	3601	0	40	59	42
41	4127	9	43	56	48
42	4728	44	55	35	82
43	5417	494	79	21	110
44	6206	263	94	45	129
45	7108	171	137	44	269
46	8142	138	157	32	372
47	9326	113	153	37	374
48	10681	92	202	54	293

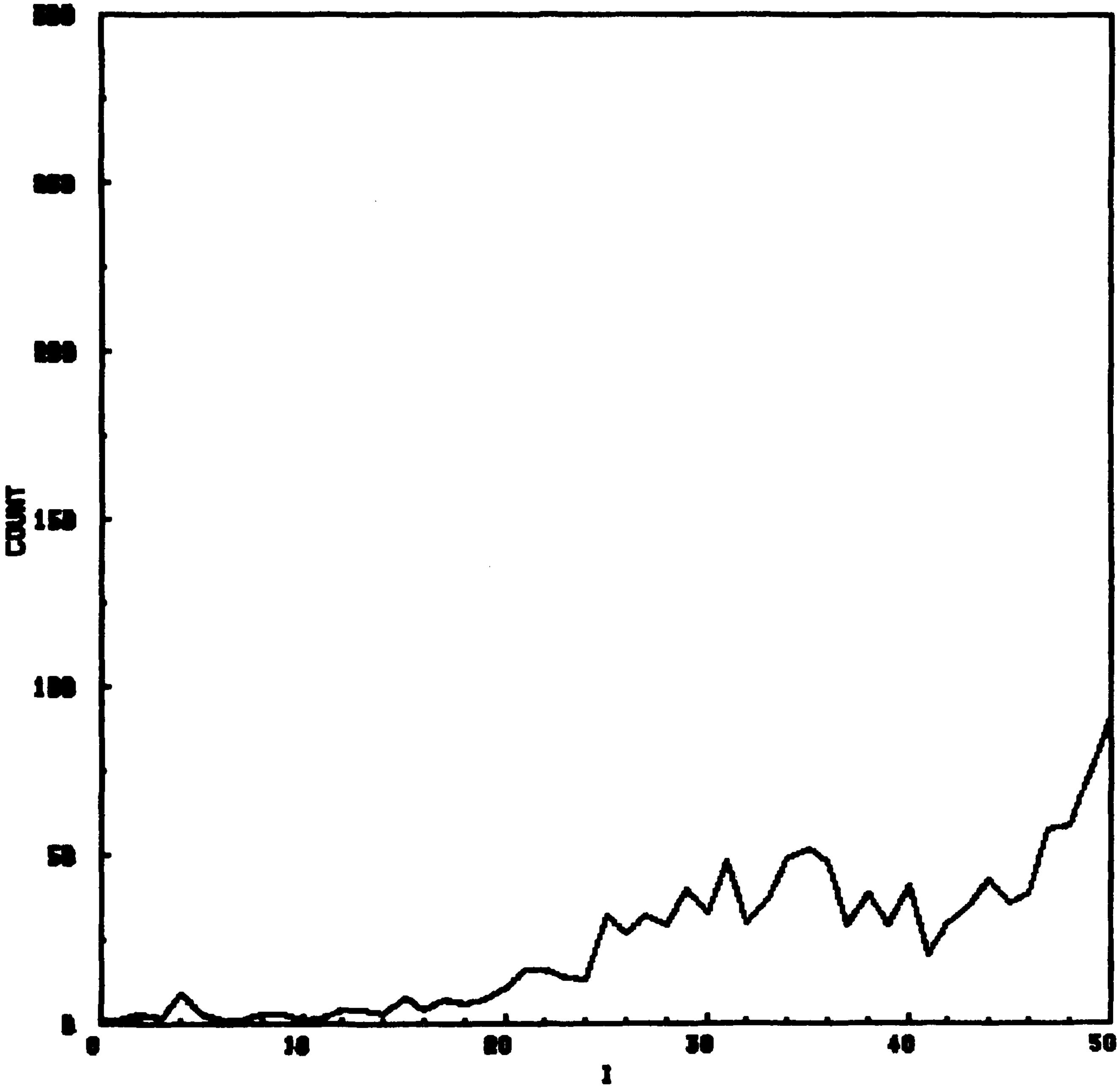

FIG. 1

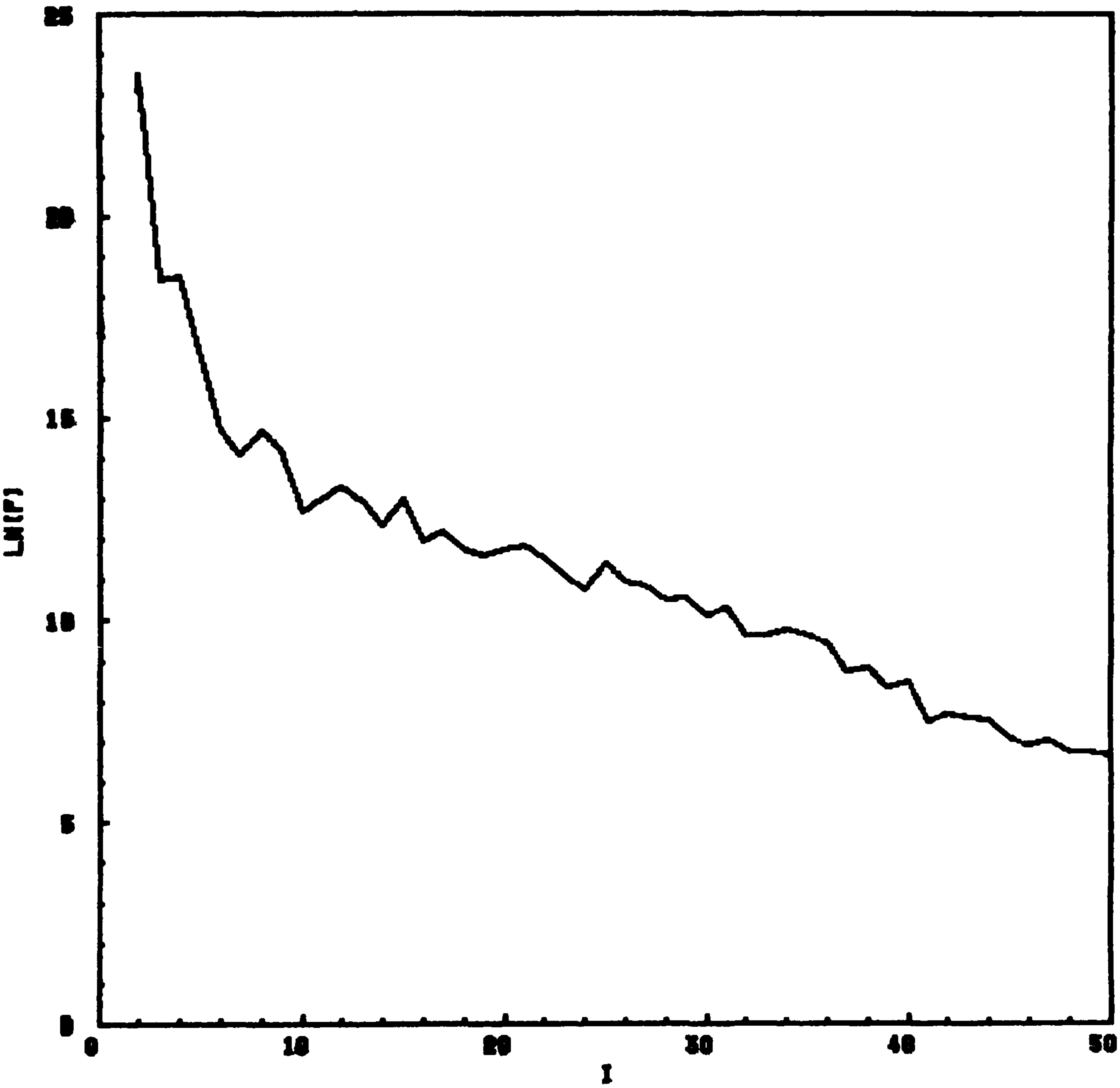

FIG. 2

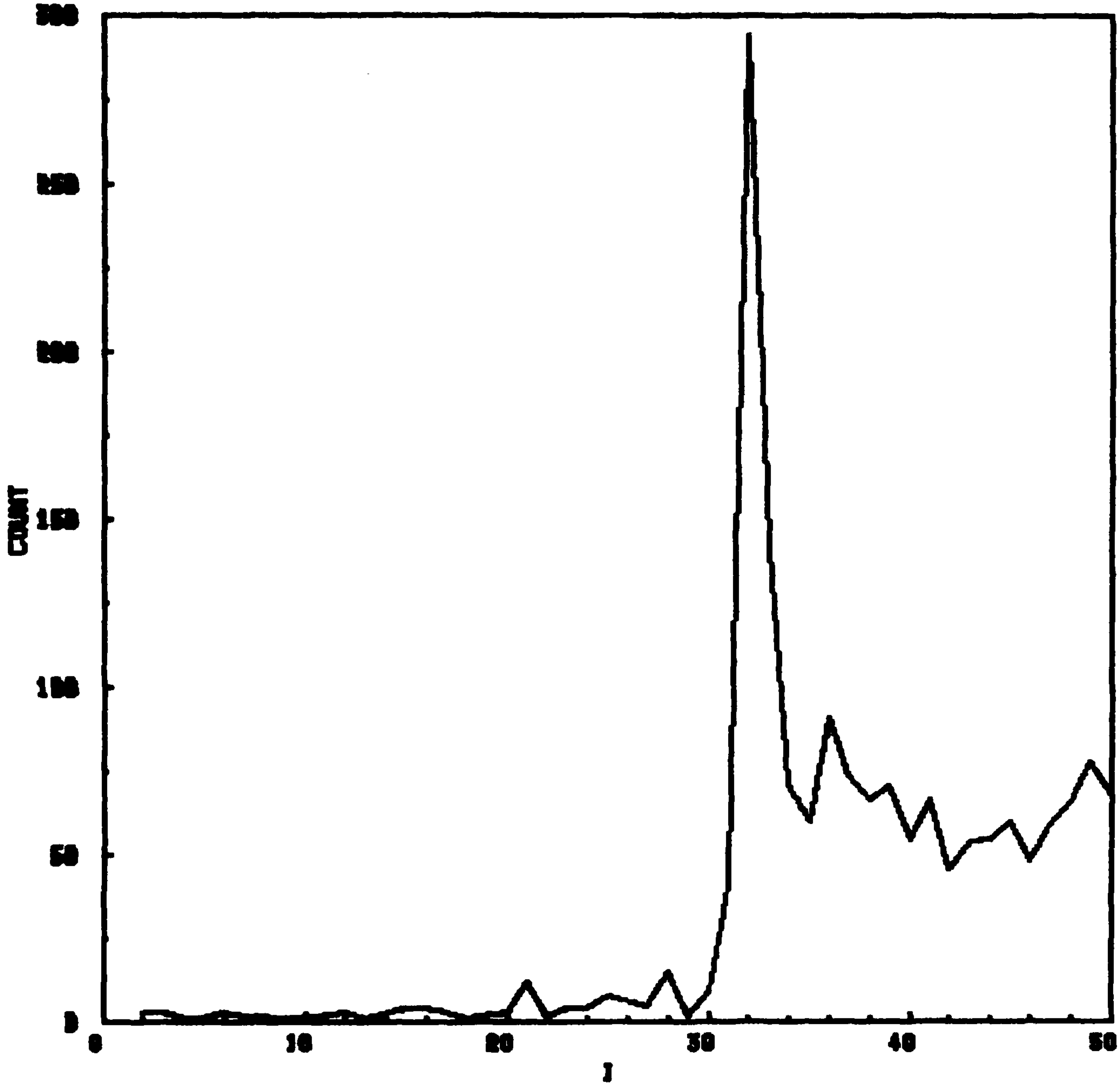

FIG. 3

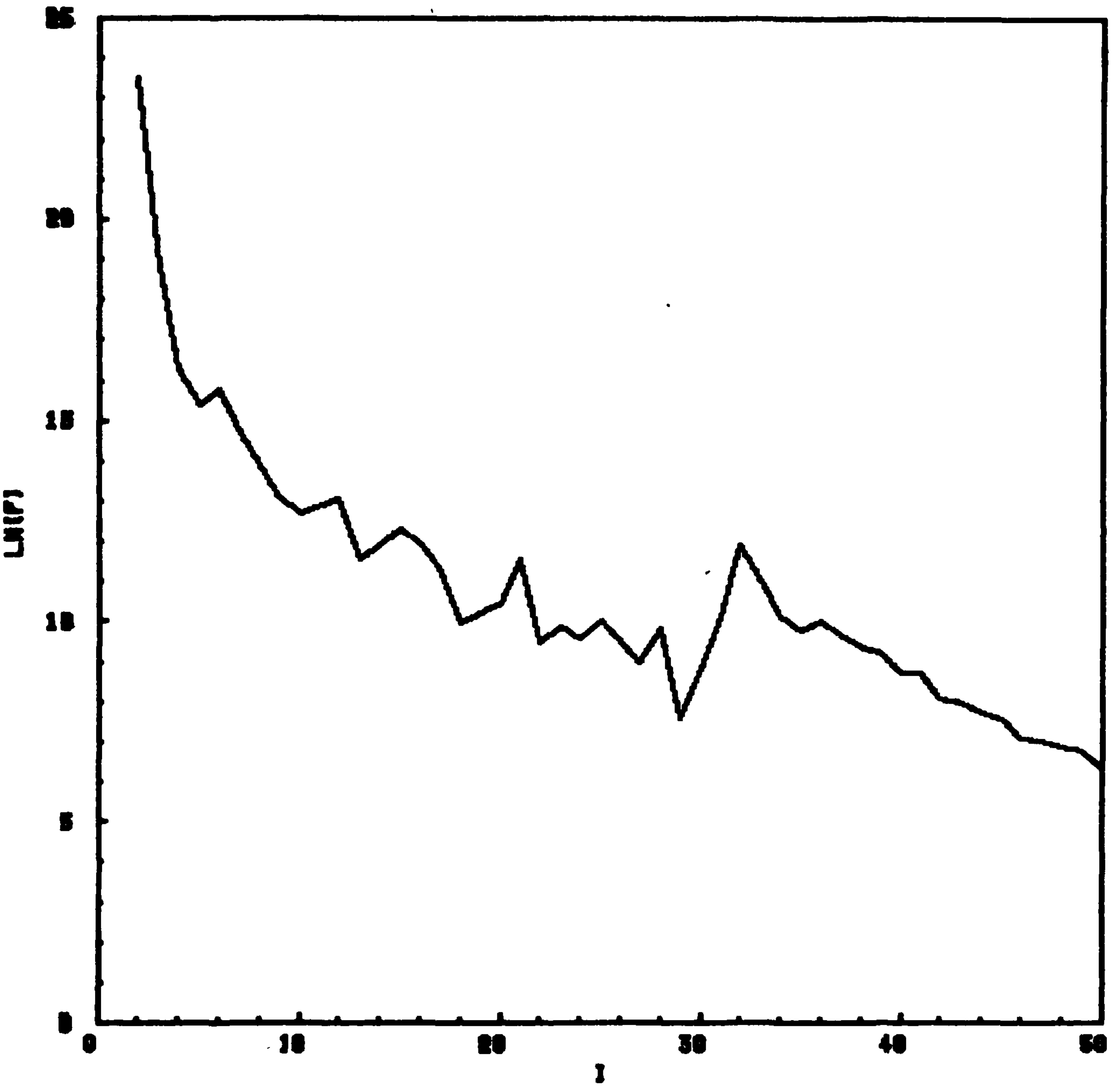

FIG. 4

THE COUNT RATIO ALGORITHM

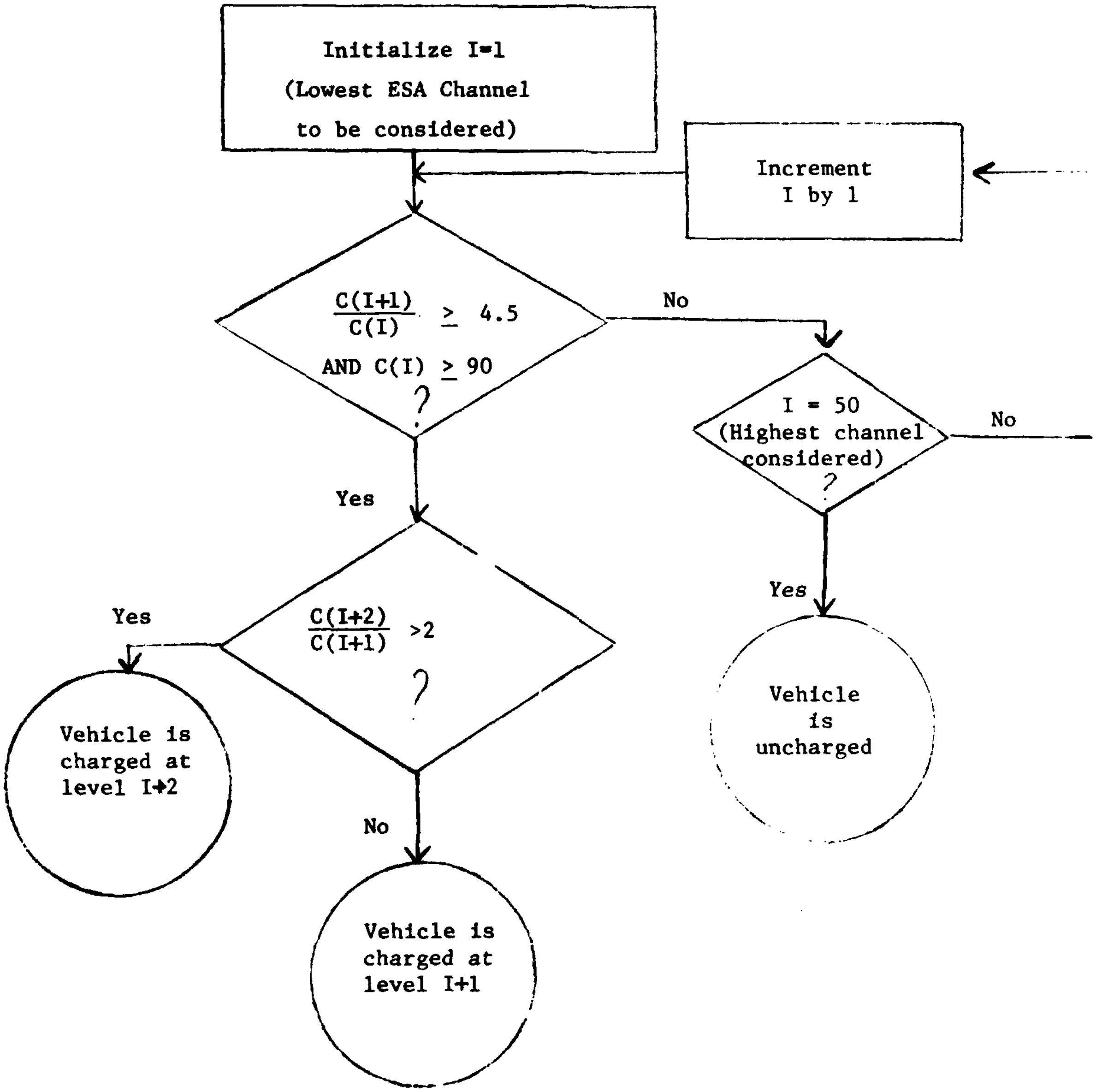

FIG. 5

THE DISTRIBUTION FUNCTION ALGORITHM

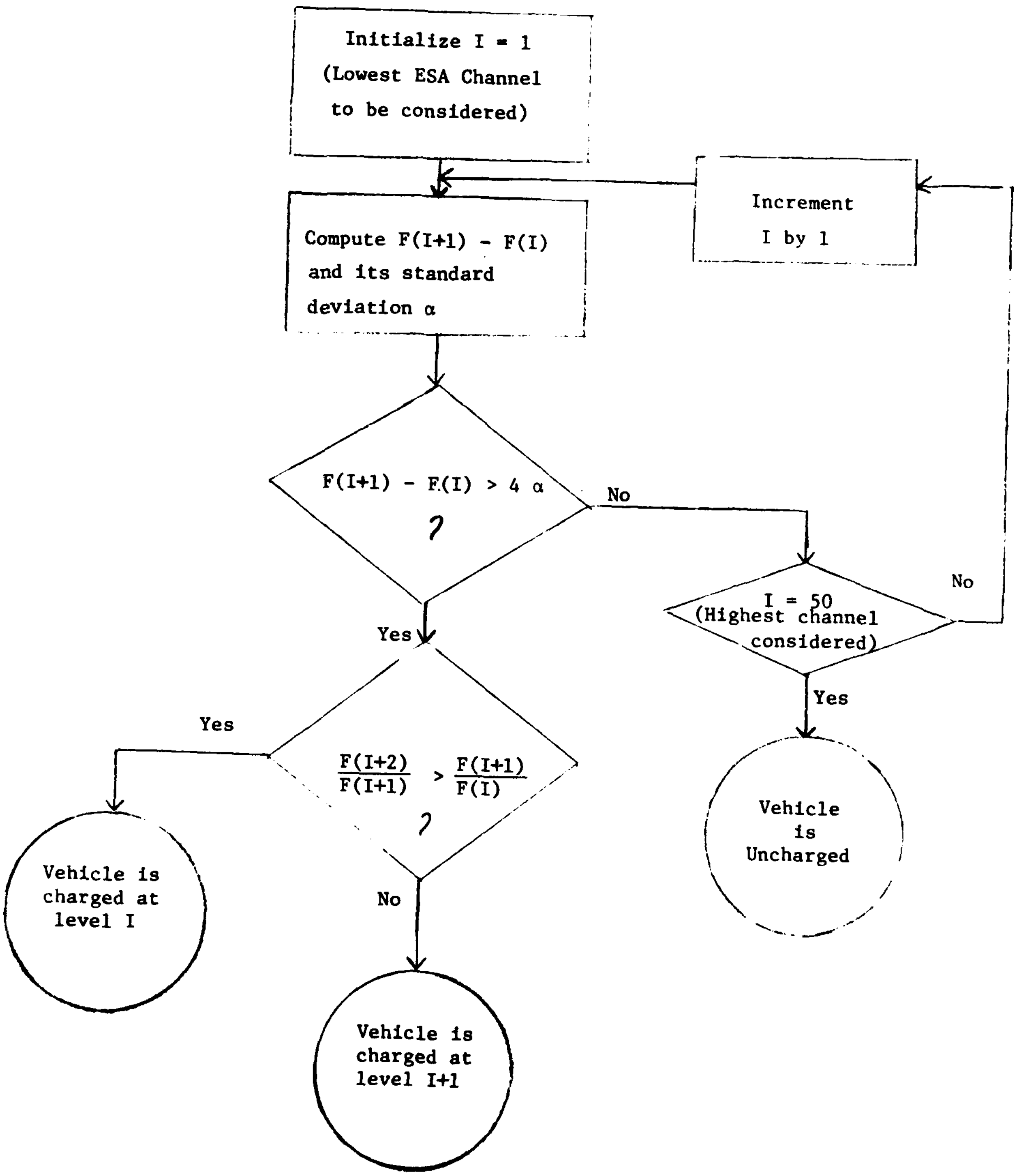

FIG. 6

FIGURE CAPTIONS

Fig. 1 Positive ion counts as a function of SC9 high energy ESA channel (I) for day 79105, time 36128, sec. U.T. The count spectrum exhibits no precipitious adjacent channel increase and is typical for the case of an uncharged spacecraft.

Fig. 2 Natural logarithm of the positive ion distribution function F as a function of SC9 high energy channel (I) for the time of Fig. 1. F exhibits the decrease with increasing energy expected for an uncharged spacecraft.

Fig. 3 Same as Fig. 1 but for time 36408, sec. U.T. The sharp peak in the count spectrum indicates spacecraft charging to the level of ESA channel 32 (-1205eV).

Fig. 4 Same as Fig. 2 but for time 36408 sec. U.T. (as in Fig. 3). There is a statistically significant increase in F at channel 32, indicating spacecraft charging to that level (-1205eV).

Fig. 5 Flow chart of the count ratio algorithm, involving comparisons of ion counts in SC9 ESA channels C(I), incorporating parameter values used in our testing.

Fig. 6 Flow chart of the distribution function algorithm, involving comparisons of the ion distribution function F(I), incorporating parameter values used in our testing.

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